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AN INTRODUCTION TO THE AFGL MAGNETOMETER NETWORK, (U)
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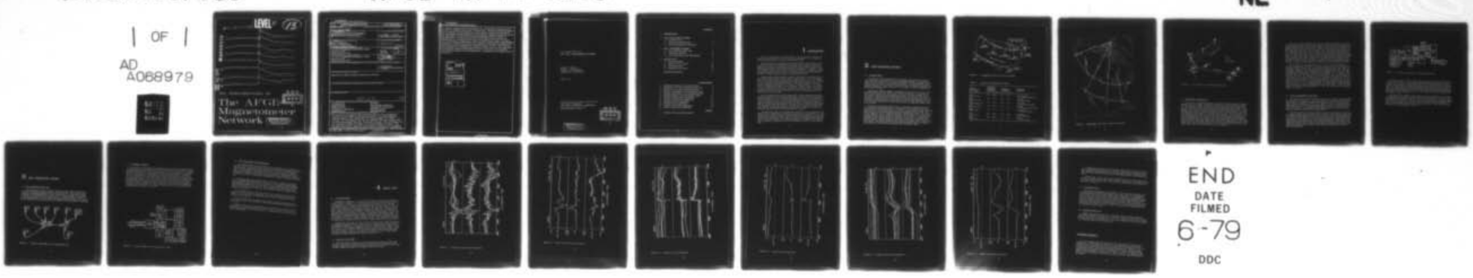

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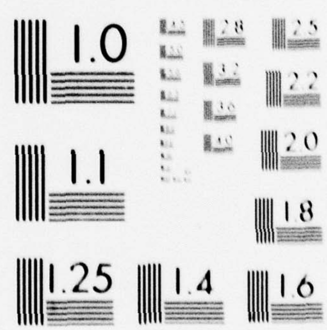

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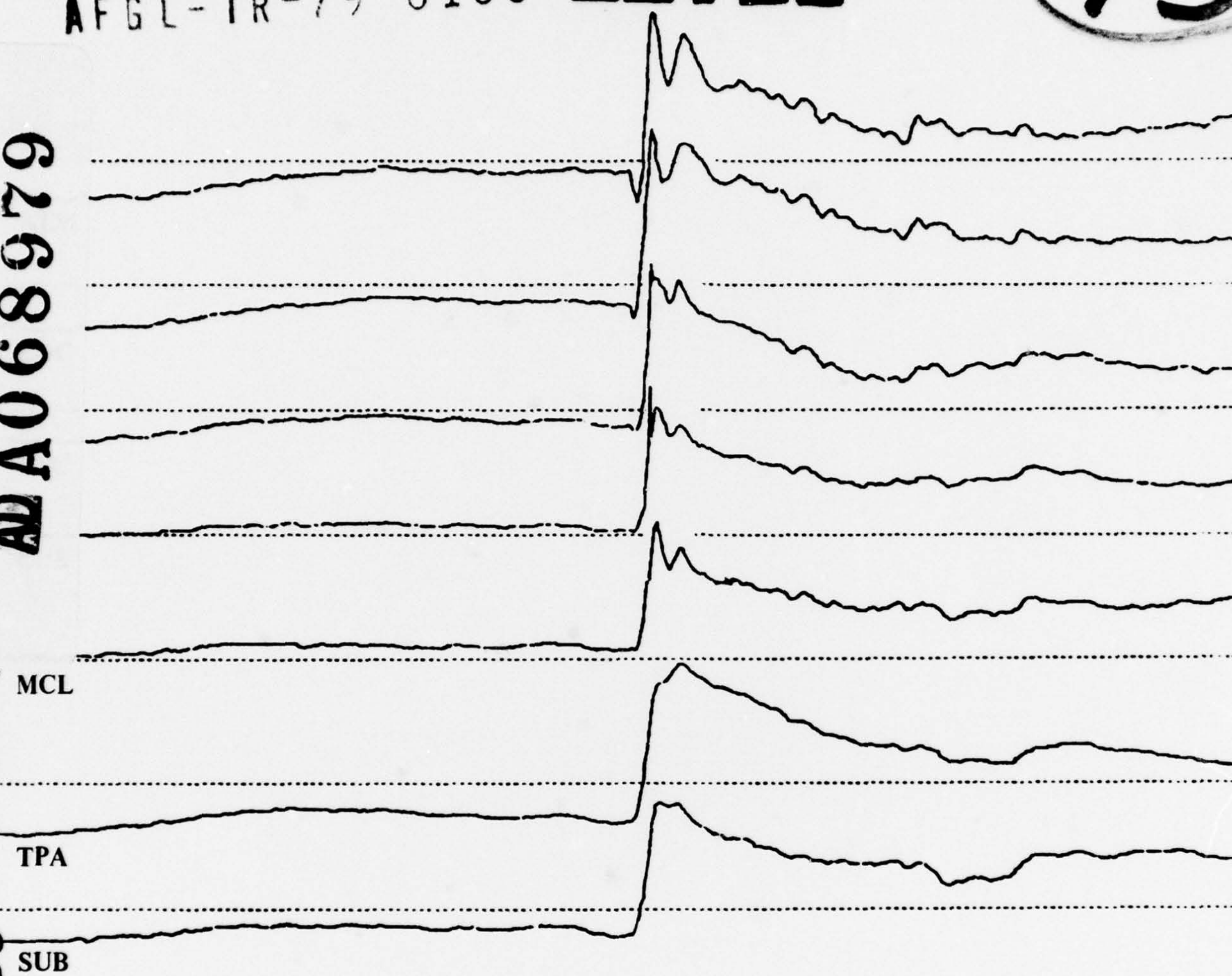

An Introduction to The AFGL Magnetometer Network

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The seven-station magnetometer network of the Air Force Geophysics Laboratory is currently in continuous operation. Five data-collection stations (Newport, WA, Rapid City, SD, Camp Douglas, WI, Mount Clemens, MI, and Sudbury, MA) form a 3800-km east-west chain at 55°N corrected geomagnetic latitude. Two others (Lompoc, CA, and Tampa, FL) are separated by 3800 km at 40°N corrected geomagnetic latitude. The principal instruments, identical at all stations, include a three-component induction-coil magnetometer to measure its time derivative. Sensitivities

degrees

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are about 0.1 gamma and 0.001 gamma-Hz, and sampling frequencies are one and five samples per second, respectively. The data-collection stations are not manned; measurements are made and processed automatically by microprocessor-based equipment at each station. Stations are synchronized and controlled remotely from the data-acquisition station at AFGL in Massachusetts. Outbound control and inbound data-return signals are transmitted on dedicated commercial voice-grade phone lines. Forward-error-correction techniques are used to assure accurate data transmissions. Operation is fulltime and continuous except for interruptions occasioned by malfunctions of the equipment or communications circuits. Data from all seven stations are processed and archived in near-real time by a dedicated minicomputer; values of the field and its time derivative are available within twenty seconds of the sampling time. Examples of the output data are presented.

AN INTRODUCTION TO

THE AFGL MAGNETOMETER NETWORK

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CHARLES W. TSACOYEANES

APRIL 1979

PLASMAS, PARTICLES, AND FIELDS BRANCH

SPACE PHYSICS DIVISION

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HANSCOM AIR FORCE BASE

MASSACHUSETTS 01731

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1 INTRODUCTION

This report summarizes the essential features of the magnetometer network constructed and operated by the Air Force Geophysics Laboratory. A more detailed description will be provided in a separate AFGL technical report.

Severe magnetospheric disturbances, called magnetospheric storms, produce a variety of adverse effects on operational military systems. The effects result from severe departures from the normal ionospheric and magnetospheric conditions upon which systems such as military communications depend for operation. The objectives of the AFGL Magnetometer Network program include the development of methods to predict magnetospheric storms in order to lessen their impact on military operational capability and the provision of realtime data to operational military systems which require a knowledge of magnetospheric conditions for optimum performance.

A magnetospheric storm produces a number of phenomena; its manifestation as a disturbance of the geomagnetic field is called a magnetic storm. The AFGL program chooses the magnetic field as the parameter to be studied because of its direct dependence on the basic processes producing the disturbance and the relative ease with which it may be measured by ground magnetometers. The practical approach chosen is to measure magnetic-field disturbances at a number of selected locations in the United States with magnetometers which cover an appropriate range of amplitude and frequency and to transmit the resulting data in real time to a central location. The data obtained are measurements of the vector magnetic field at intervals of one second and measurements of the vector time derivative of the field for fluctuations with periods between one and 1000 seconds.

Each instrumented data-collection station (DCS) operates continuously and automatically, unattended except for routine maintenance. Five stations are located approximately along the line of 55 ^{o}N corrected geomagnetic latitude, and two additional stations lie along the line of 40 ^{o}N corrected geomagnetic latitude. Data from each station are returned in real time on commercial voice-grade communication circuits to a single data-acquisition station (DAS) located at the Air Force Geophysics Laboratory at Hanscom Air Force Base, Massachusetts. The DAS performs realtime processing, reduction, and display of the data and stores processed data in a permanent file for subsequent analysis. All facilities involved are dedicated to the program, so essentially uninterrupted operation over an extended time period is possible.

The important features of the magnetometer network are (a) the ordered array of stations, (b) the measurement of both the vector field and its time derivative at a rapid sampling rate by identical instruments producing directly comparable data, (c) the transmission of these data in real time to AFGL, (d) the automatic realtime processing, storage, reduction, and display of the combined data, (e) the essentially uninterrupted operation for a period of several years, and (f) the ability of the network to be expanded and/or operated in conjunction with networks established elsewhere by other organizations.

2 DATA COLLECTION STATIONS

2.1 STATION SITES

The first five stations instrumented for the program were spaced across the northern United States at about 55 °N corrected geomagnetic latitude. Two subsequent stations span the southern United States at about 40 °N corrected geomagnetic latitude. Each is located on the site of a Government installation. The station locations and installation names are shown in Figure 1 and listed in Table 1 with their geomagnetic and geographic coordinates. Their relationship to the Canadian and Alaskan magnetometer arrays is shown in Figure 2.

Specifications relative to magnetic characteristics of the sites were not made severe, since basic objectives do not require a very accurate measurement of the steady and slowly varying components of the magnetic field. For each station, magnetic noise in the frequency range of measurement and field gradients in the vicinity of the sensors were kept to a tolerable level by selecting areas located away from man-made noise and conducting a simple site survey to assure adequacy. The horizontal gradient in the vicinity of the sensors probably does not exceed 0.1 gamma per foot, and magnetic noise in the frequency range of 0.01 to 0.3 Hz did not exceed 20 milligammas (peak to peak) at the worst site.

All sites are provided with electrical power, a voice-grade communications line for data transmission, and telephone service. Construction at the site includes four instrument piers and one instrument shelter. Each of three piers supports one single-component searchcoil sensor, and the fourth supports the three-component fluxgate sensor. The shelter houses the associated instrument electronics, data-handling circuitry, and communications equipment. Figure 3 shows the layout of a typical station. The searchcoil piers are about 300 feet from the shelter and separated from each other by at least 30 feet; underground cables connect the sensors to circuitry in the shelter. The fluxgate pier is about 90 feet from the shelter and at least 20 feet from the nearest point of buried searchcoil cable; a separate underground cable connects the fluxgate sensor to its circuitry in the shelter. The location of sites on Government installations makes it possible for local personnel to perform simple maintenance and make routine checks.

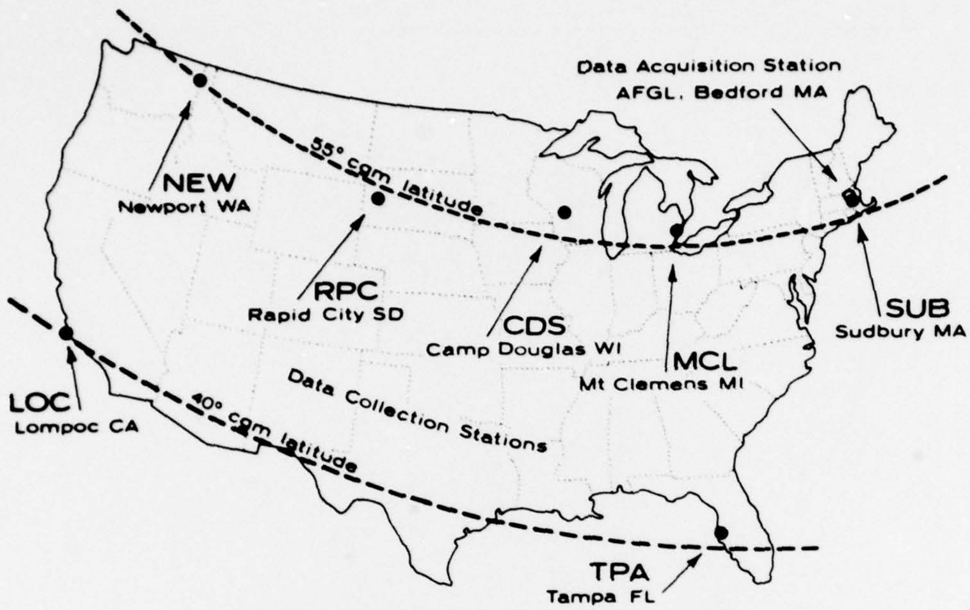

FIGURE 1. Geographical locations of the network stations

TABLE 1. Locations of the data-collection stations

Station symbol/name (post office)	Corrected geomagnetic coordinates N Lat	Corrected geomagnetic coordinates E Long	Geographic coordinates N Lat	Geographic coordinates W Long	Government installation
NEW Newport, WA	55.2	299.6	48.3	117.1	USGS Newport Geophysical Observatory
RPC Rapid City, SD	54.1	317.3	44.2	103.1	Ellsworth Air Force Base
CDS Camp Douglas, WI	56.3	334.2	44.0	90.3	Volk Field (National Guard Base)
MCL Mt Clemens, MI	55.8	344.8	42.6	82.9	Selfridge Air National Guard Base
SUB Sudbury, MA	55.8	1.9	42.2	71.3	Army Natick Laboratory Annex
LOC Lompoc, CA	40.2	300.6	34.7	120.6	Vandenberg Air Force Base
TPA Tampa, FL	40.7	344.9	27.8	82.5	MacDill Air Force Base

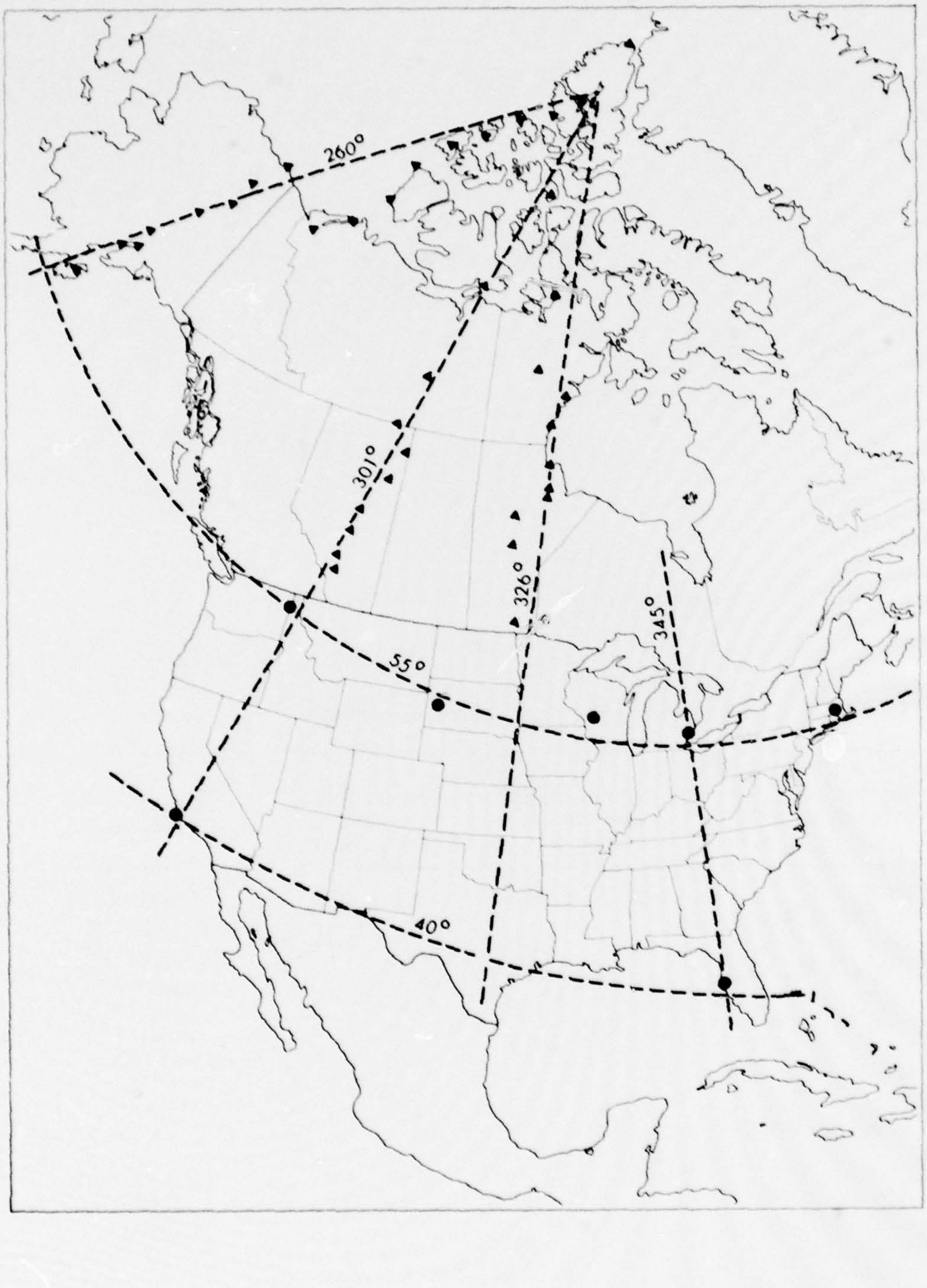

FIGURE 2. Relationship of the AFGL network to other arrays

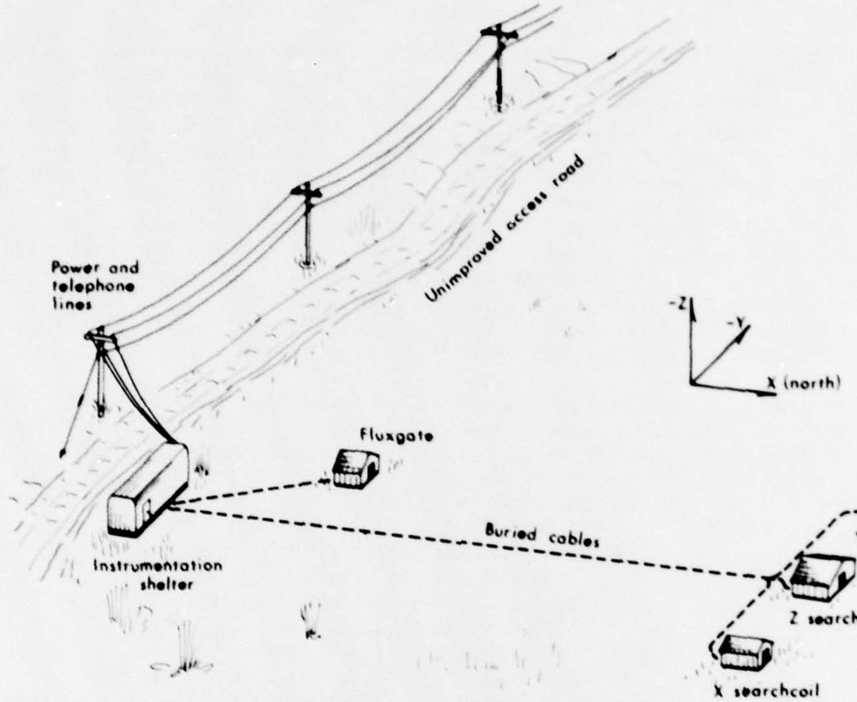

FIGURE 3. Site layout for a typical data-collection station

2.2 SCIENTIFIC INSTRUMENTS

One of the two principal instruments at each DCS is the three-component fluxgate magnetometer. It is actually three separate single-component magnetometers combined into one instrument, sharing a common power supply, electronics, and instrument housing. The instrument utilizes both coarse and fine feedback coils which produce a nulling field at each sensor to cancel the ambient component field being measured. Current through each coarse feedback coil is incremented in units corresponding to 64 gammas until the field is nulled to within 64 gammas, the range of the fine feedback coil. Current through the fine feedback coil is the processed output of a sense coil, which results from amplification, filtering to pass only the desired frequency, and demodulation to convert the amplitude to a dc current. This current is proportional to the remaining field (not nulled by the coarse feedback) and is directed through the fine feedback coil to make the total nulling field nearly equal to the ambient component field. The magnetometer outputs are the analog voltage which produces the fine-feedback current and the binary count of the coarse-feedback steps. The fine output is low-pass filtered to avoid aliasing which might otherwise result from the low sampling rate.

Each of the fluxgate magnetometers meets the following performance specifications. The fine-feedback section, with a dynamic range of plus and minus 64 gammas, has an output sensitivity of 160 mv/gamma (i.e., a full-scale output of 10.24 volts, positive or negative) with a full-scale accuracy of 0.05 gamma. The output filter is a low-pass two-pole Butterworth type with a -3db corner at 0.3 Hz. The coarse-feedback section, with a dynamic range of -65,536 to +65,472 gammas, has a sensitivity of 64 gammas/step (i.e., a full-scale output of 1024 steps, positive and negative, with the first positive step being zero field). The output is an 11-bit binary number (including sign) indicating the number of steps incremented. Accuracy is 0.2 percent at full scale positive and negative, with a deviation not exceeding 1 gamma from a straight line between full-scale values. Temperature drift is less than 1 gamma/^{o}C in both scale factor and zero-field accuracy. The three component sensors are aligned to within 0.5 degree of orthogonality and are mounted in a single housing equipped with leveling screws and bubble-type indicators.

The second of two principal instruments at each DCS is the three-component searchcoil magnetometer. It consists of a separate sensor unit for each of three components and a single electronics unit. Variations in the magnetic field, dH/dt, induce a proportional voltage in a long solenoid wound on a highly permeable core. This signal is amplified and filtered for compatibility with the sampling system. The sensor unit comprises about 30,000 turns on a laminated moly-permalloy core. A Faraday shield surrounds the core and winding, and an outer jacket of PVC pipe and endcaps encases the entire sensor unit. Two leads from the sense winding and one from the shield are connected by cables to the electronics unit. In the frequency range of 0 to 5 Hz, the sensor alone has a sensitivity of 137 microvolts/gamma-Hz. The winding has L = 605 henrys, R = 438 ohms, and C = 1350 picofarads. Four gain settings are selectable on the amplifier (about 5, 10, 50, and 100 times 1000) to provide overall instrument sensitivities of about 0.5, 1, 5, and 10 volts/gamma-Hz. The output filter is a four-pole Butterworth type which provides an essentially flat response from 0.001 to 0.5 Hz; the -3db point is at 1.4 Hz and the -10db point is at 2.2 Hz. The -3db point of the unfiltered output is at 350 Hz.

2.3 DATA-CONDITIONING CIRCUITRY

The circuitry which gathers and processes the data at each DCS is shown in simplified schematic form in Figure 4. The DCS is operated by a microprocessor-based unit which receives a network-control signal (transmitted from AFGL) which provides time synchronization and polling. Instruments are sampled according to a stored program; digital outputs are read directly, while analog outputs are read by addressing the appropriate input channel of a 32-channel analog-to-digital converter. The microprocessor orders the data into a standard frame format, adds redundancy for error-rate improvement, and outputs a serial bit stream for transmission.

Data from each DCS are collected during a ten-second sampling interval and sent as a data frame during a subsequent one-second transmission interval assigned to that DCS. The fluxgate magnetometer is sampled once per second and the searchcoil magnetometer is sampled every 200 milliseconds. The total output from the two magnetometers (all components) is 189 words for every ten-second sampling interval. Other data in each frame (frame synchronization, frame count, station identification, status monitors, and reference voltages and temperatures for magnetometer calibrations) bring the total basic requirement to 202 words. The system was designed to accommodate a frame of 240 words; the remaining 38 are available as spare analog and digital inputs for use by future instrumentation.

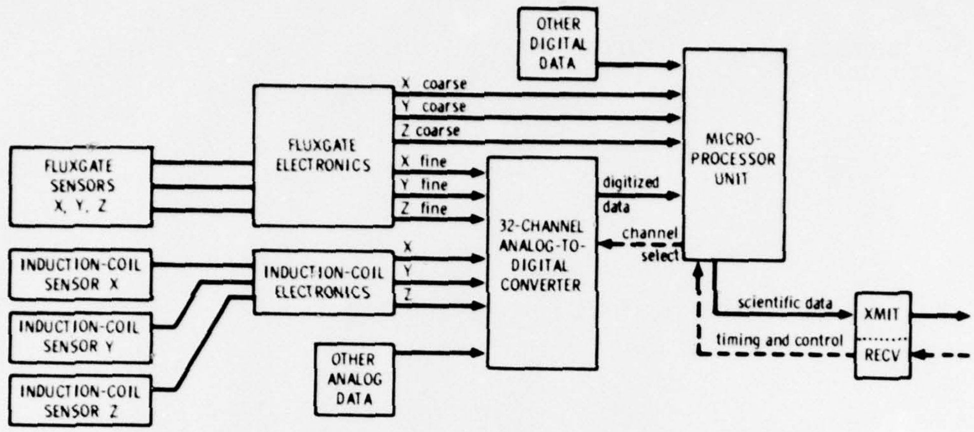

FIGURE 4. Schematic representation of a data-collection station

All data words are 11 bits in length, with four parity bits added for error-correction purposes. Thus, a frame of data, as prepared for transmission, consists of 240 15-bit words; these are stored in a matrix constructed of 15 240-bit shift registers. Since one sampling interval follows the preceding one without pause, while data from each interval need to be stored until the assigned transmission time (between zero and ten seconds later), two identical matrices are used in alternation, each being filled in one ten-second interval and storing/transmitting in the next. The output is a serial stream of 3600 bits (240 words of 15 bits each) clocked out at a rate of 4800 bits/sec; the duration of the bit stream is therefore 750 ms.

In addition to the redundant coding obtained by using four parity bits, a technique of interleaving bits from all the words is used to reduce the effect of a noise burst lasting longer than the duration of one bit. The first bit of each word in sequence is transmitted, then the second bit of each word, and so on until the frame is complete. Bursts of errors are thus spread out to cause no more than one bit error per word (which is fully correctable) unless a burst persists for longer than 50 ms. Errors in the data from line noise are entirely negligible in practice.

3 DATA ACQUISITION STATION

3.1 THE COMMUNICATION LINK

The data-acquisition station at AFGL is linked to the data-collection stations by a voice-grade communications network leased from Western Union. The network is full-duplex (i.e., affording simultaneous two-way communication, an outlink and an inlink). It consists of nine segments laid out to form a tree, as shown in Figure 5, with AFGL at the base and a DCS at the end of each branch. An outbound signal, therefore, can be sent simultaneously to all of the DCS's, but they must respond in turn. At each hub the first branch with traffic seizes the line and holds it until its transmission is completed.

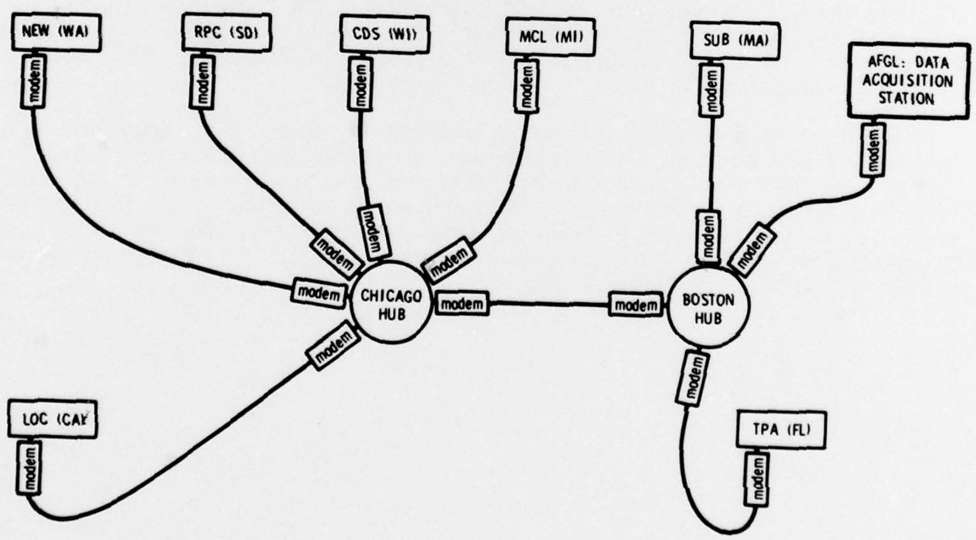

FIGURE 5. Schematic representation of the communication link

3.2 NETWORK CONTROL

The functions of the DAS may be grouped in two areas: network control, discussed in this section, and data reception and processing, discussed in the next section. A schematic representation of the DAS is shown in Figure 6. Network control is accomplished through the generation of a network-control signal, which is referenced to a master system clock and transmitted continuously on the communications outlink. Ten stations may be accommodated by the communications system. The inlink is used for data return, time shared by all of the DCS's, each of which transmits a frame of digitized data in a programed sequence. Each DCS responds according to instructions contained in the network-control signal, which synchronizes the taking of data samples by the scientific instruments and the transmission of these data at the proper time. Signal-propagation delays are precisely compensated so that sampling times at all stations are simultaneous to within several milliseconds. The details of sampling, storing, and transmitting follow a stored microprocessor program of the DCS.

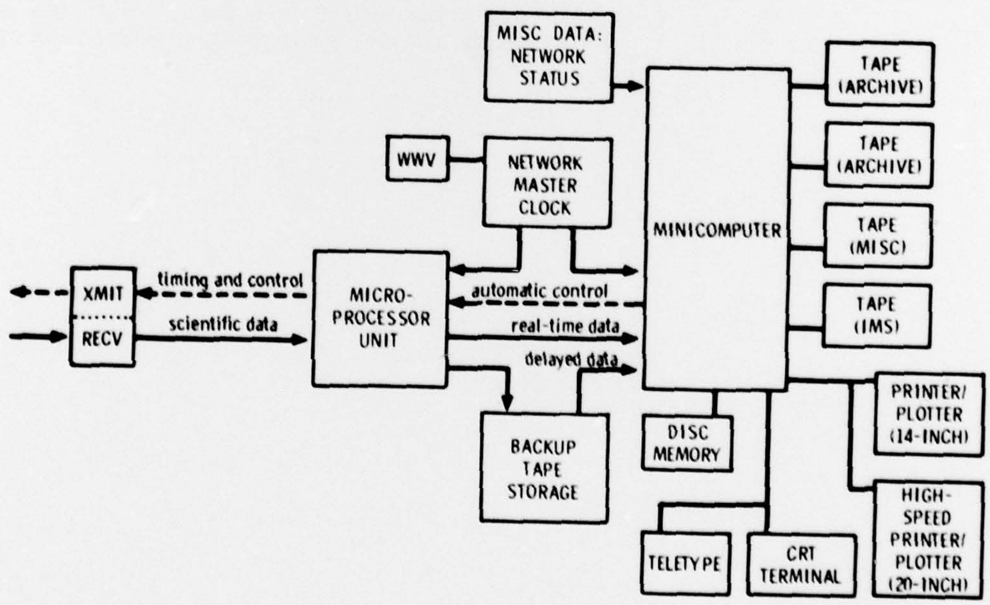

FIGURE 6. Schematic diagram of the data-acquisition station

3.3 DATA RECEPTION AND PROCESSING

The serial bit stream of data returned by the network flows into the DAS microprocessor unit which recognizes frame-synchronization information, reconstructs the 15-by-240 data matrix, decodes and corrects each word on the basis of parity information, labels each frame with the correct time, and passes it to the minicomputer, where the data are then available in quasireal time to any user program. One program operates continuously to archive all raw data on magnetic tapes, on which the data are compressed and reordered without any information being discarded. These are referred to as *archive tapes.*

Up to the present time, programs which use the data have needed to incorporate means of checking and editing the data, since several types of equipment malfunction have occasionally caused faulty data to be produced. An automatic cleaning procedure, using algorithms designed to reject faulty data, is currently being developed which will result in the availability of the *basic user tapes* described in the next section. Some derived data, such as various averages and activity indices, will also be computed for inclusion on these tapes.

At any particular time, all data received during the preceding two hours are also retained on the disc memory for immediate access. These data will be examined frequently by an automatically scheduled program to provide the near-realtime results discussed in the next section.

The CRT terminal and a high-quality printer-plotter permit graphical presentations of the basic data and of derived results. Current data presentations are illustrated in the next section.

Currently, a failure of the minicomputer system results in the loss of all data from the network, since the backup tape storage shown in Figure 6 has not yet been completed; this system will divert unprocessed data to a large-capacity tape recorder for later retrieval and archiving

4 OUTPUT DATA

4.1 MAGNETOGRAMS

Magnetograms produced by the network minicomputer currently follow the format shown in Figures 7 through 12. A separate plot is produced for each station, along with a composite plot on which the traces of all stations are superposed. The amplitude scale (ordinate) for each station is adjusted automatically to keep the trace on scale, and these differing scales are retained in the composite. The time scale (abcissa) can be selected. Three standard time scales have been chosen for routine use: (1) Daily magnetograms, covering 24 hours from midnight to midnight UT, provide an overall picture of daily activity and the occurrence of storms. (2) Two-hour magnetograms, a 12-fold magnification, permit the identification of sudden commencements and similar features. (3) Twelve-minute magnetograms, a further 10-fold magnification, plot all data samples without averaging and afford the highest resolution. The daily plots are routinely made and filed every day, so copies can easily be provided to users. The expanded plots are usually produced from the archive tapes after the time period of interest has been identified.

Network data for the day 9052 (52nd day of 1979) have been chosen for the sample magnetograms reproduced here; they show a sudden commencement at about 0302 UT and disturbed conditions for the remainder of the day, including several sudden impulses near 1600 UT. The 24-hour composite and Newport plots are shown as Figures 7 and 8. The two-hour plots for 0200 to 0400 UT (chosen to include the sudden commencement) are shown as Figures 9 and 10. The twelve-minute plots for 0258 to 0310 UT (again including the sudden commencement) are shown as Figures 11 and 12. Plots from stations other than Newport have been omitted to conserve space

4.2 DIGITAL DATA TAPES

Raw data from the network are recorded in chronological order on archive tapes. The data on these tapes are reformatted and compressed, but no information has been discarded. Magnetograms and other results are currently produced from the archive tapes, so editing routines are required in the programs which produce them.

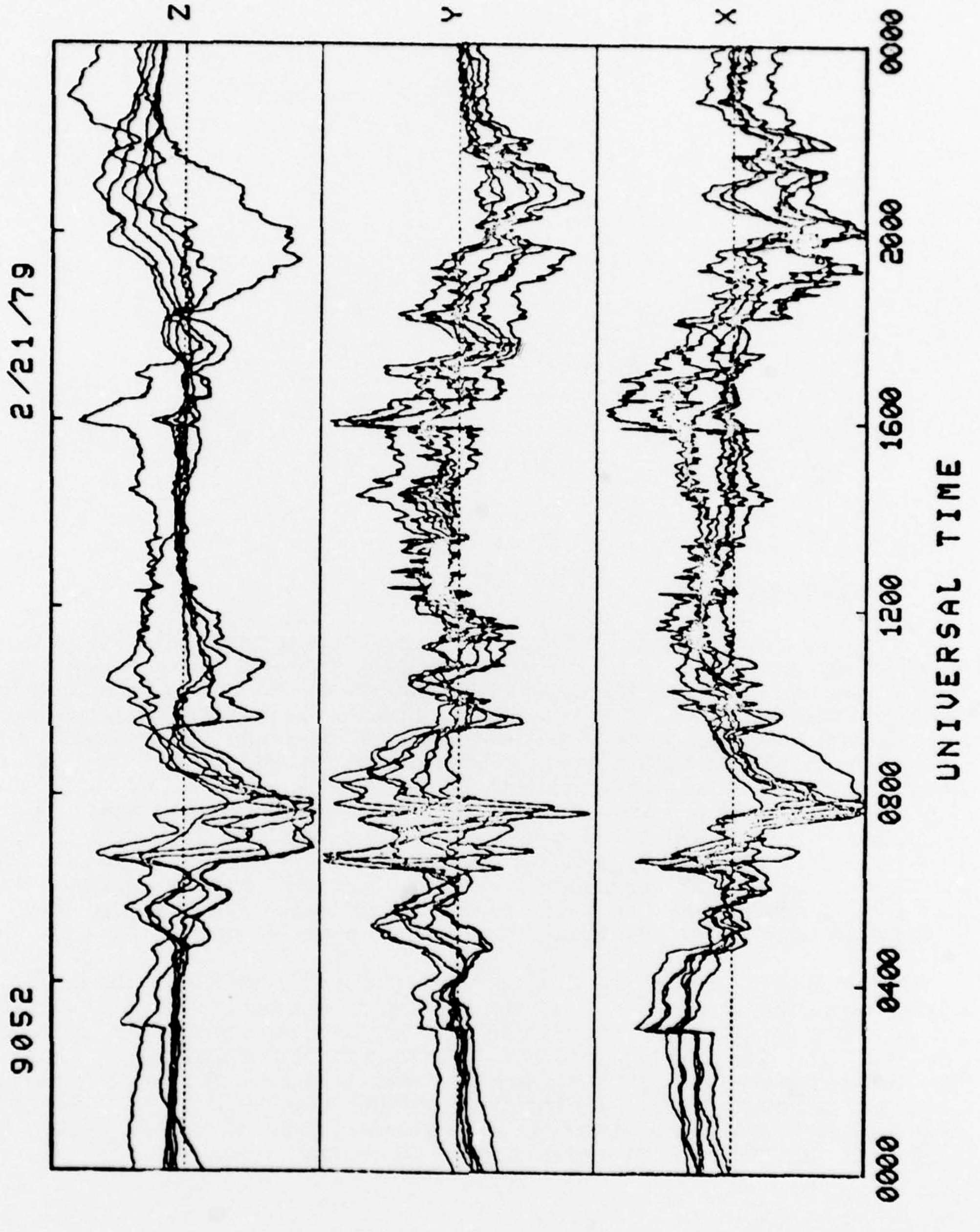

FIGURE 7. Composite twenty-four-hour magnetogram

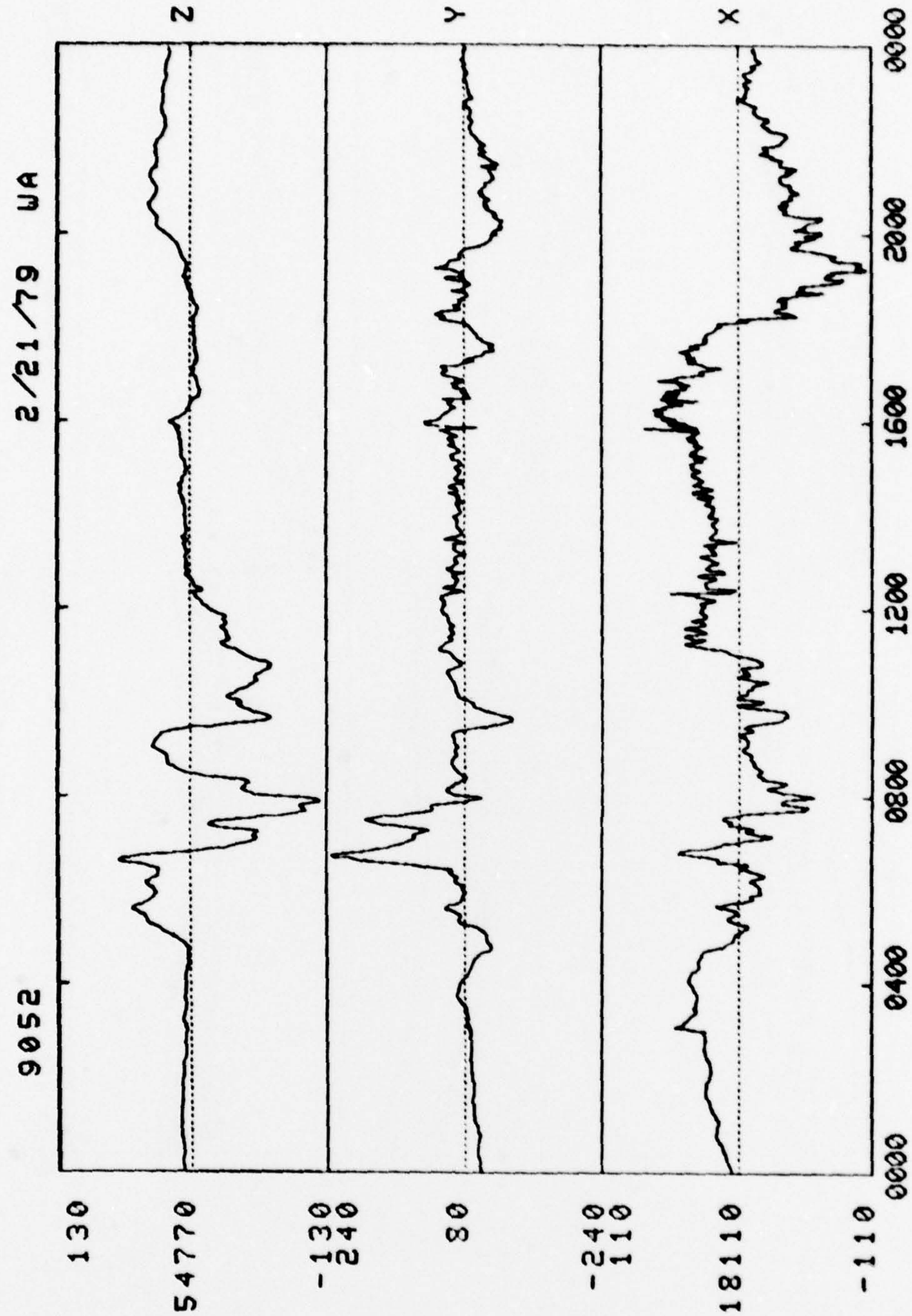

FIGURE 8. Newport twenty-four-hour magnetogram

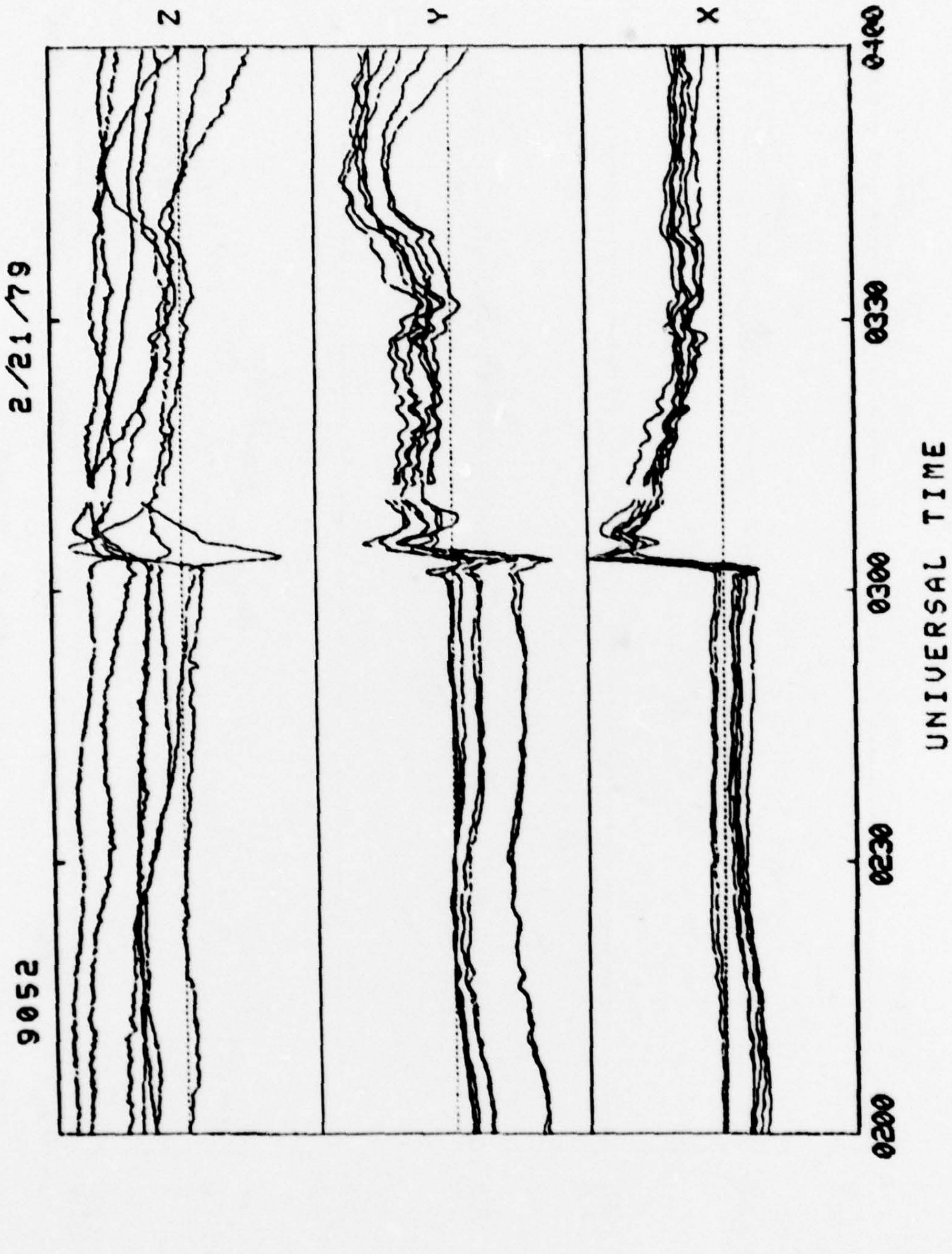

FIGURE 9. Composite two-hour magnetogram

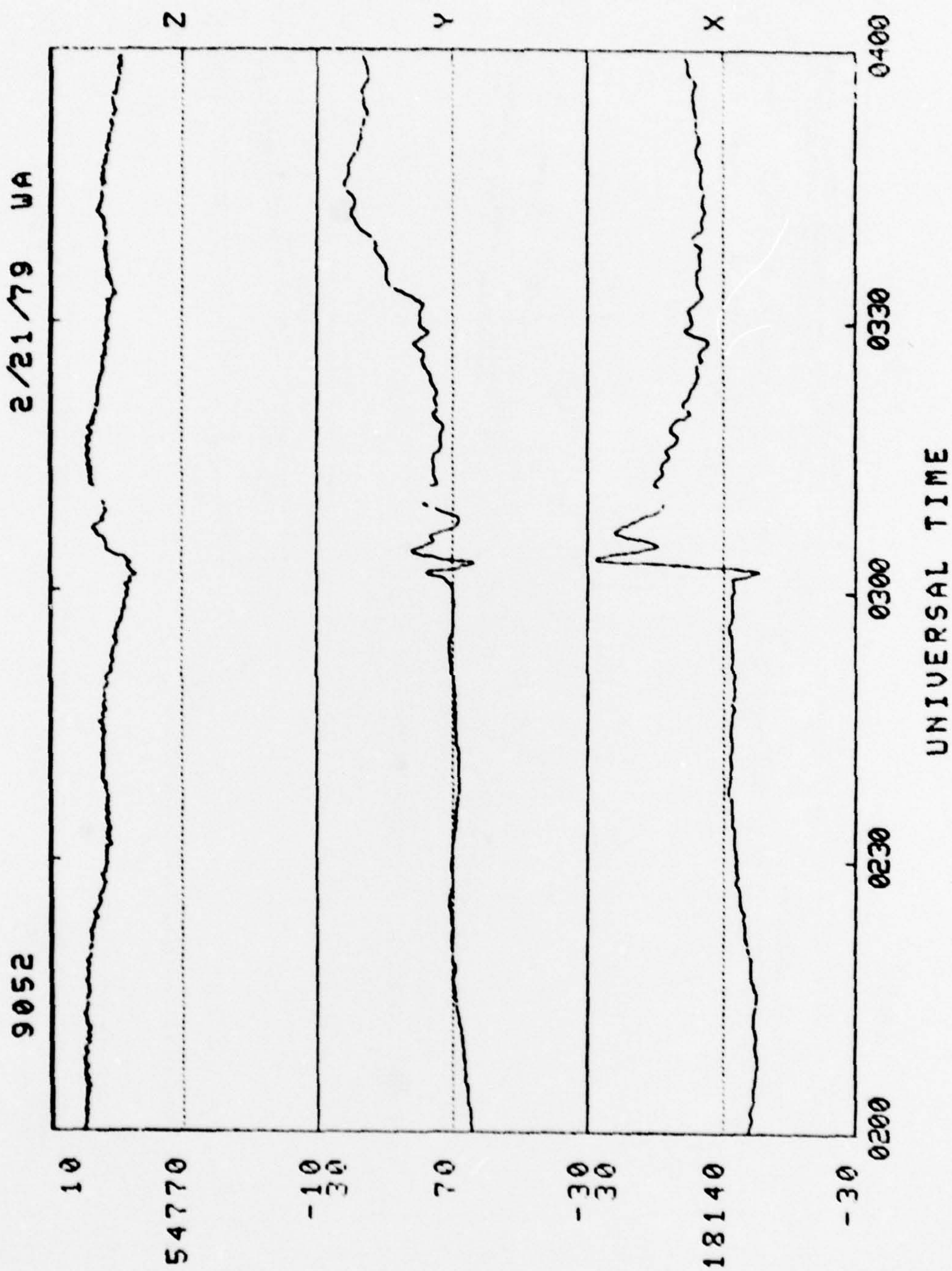

FIGURE 10. Newport two-hour magnetogram

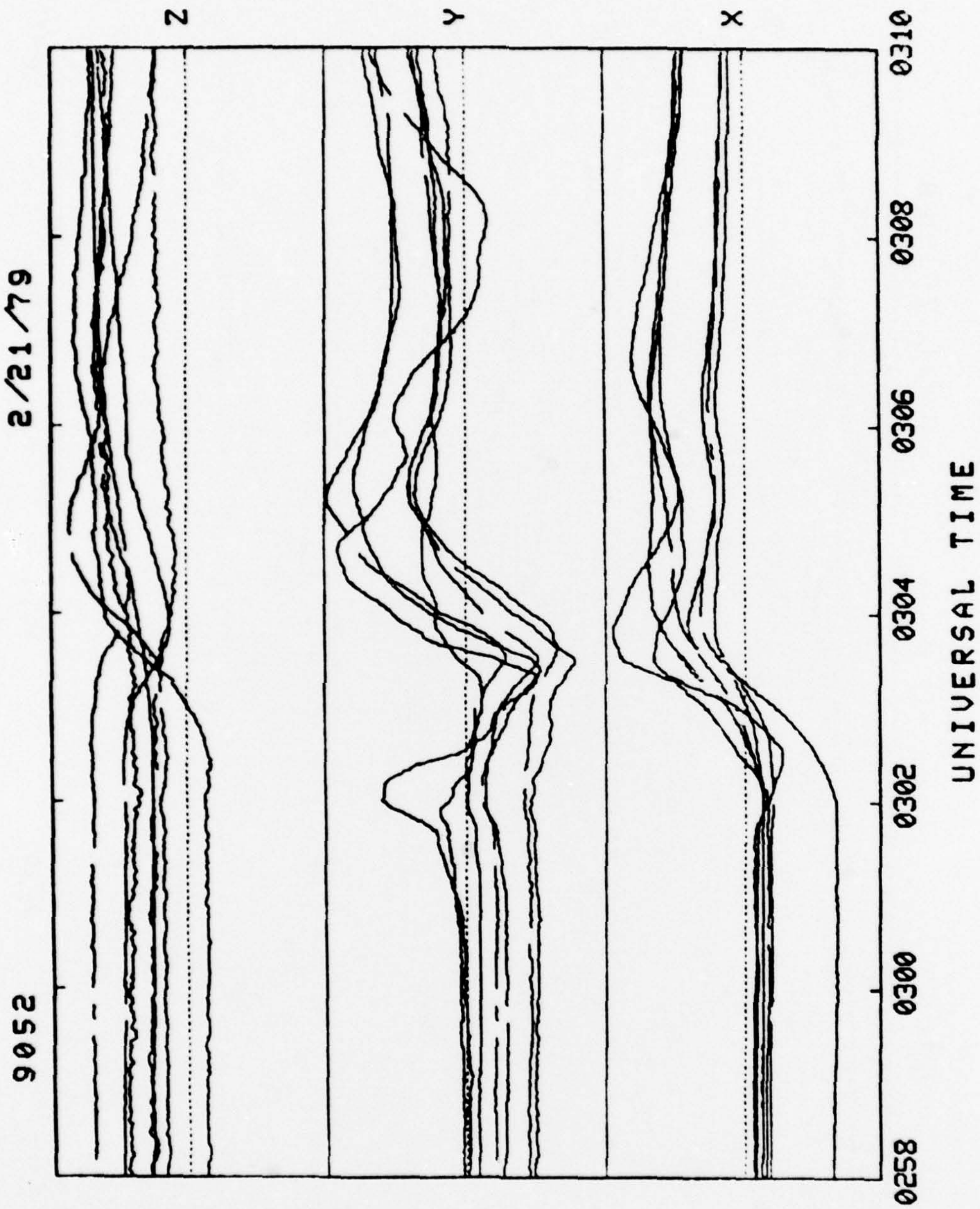

FIGURE 11. Composite twelve-minute magnetogram

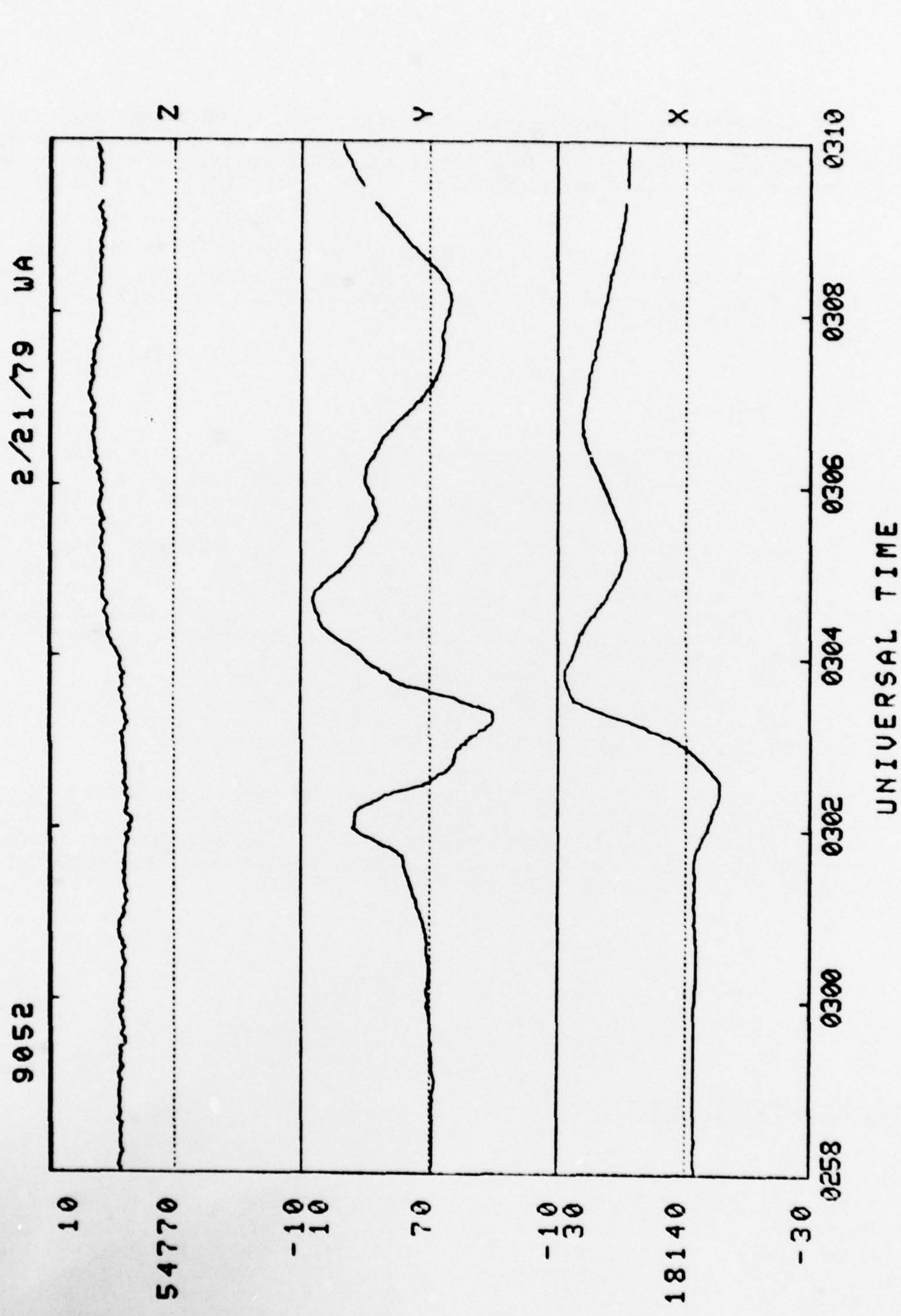

FIGURE 12. Newport twelve-minute magnetogram

A second series of tapes, the *basic user tapes*, will contain all raw data which survive an editing procedure, along with a few derived parameters such as averages and indices, arranged in compressed blocks covering one-minute intervals. Routines to access and unpack these tapes will be available, and user programs will not need editing procedures.

Another series of tapes is being made for World Data Center A; these tapes include only the one-minute average values from the fluxgate magnetometers at all stations. Each tape covers a period of one month. Other routine or special tapes will be specified in the future as needs arise.

4.3 REALTIME DATA

The network minicomputer has the capability of doing some data reduction in real (or near-real) time and automatically providing the results to users via an appropriate communication link. The first such system is under construction to be operational by fall of 1979; it will provide special 15-minute alerts and 90-minute magnetometer ranges from all stations to the Air Weather Service (AWS) at Offutt AFB near Omaha, NB, via an existing teletype network. In this sytem, the minicomputer delivers data every 15 minutes to a fully automated microprocessor-based responder, which constructs formatted messages and transmits them to the AWS computer. It is expected that a realtime estimate of Kp and a realtime detection of sudden commencements and impulses will also be incorporated into this system

4.4 REQUESTS FOR DATA

Inquiries and requests for data may be directed by mail to Dr. David J. Knecht, AFGL (PHG), Hanscom AFB, MA 01731, or by phone to Knecht (617-861-3828), Tsacoyeanes (617-861-3827), or Hutchinson (617-861-3713). (Autovon numbers are the exchange 478 followed by the last four digits given.) Data will be furnished to the extent permitted by the available manpower and computer time.

ACKNOWLEDGEMENTS

The AFGL Magnetometer Network evolved from a proposal by P. Coleman and R. McPherron for a network linked by satellite relay. Fluxgate magnetometers and data-handling circuitry were produced by R. Snare, J. Means, and F. R. George of UCLA, who also purchased and tested the searchcoil magnetometers provided by Geotronics. The communications link was assembled and operated by Western Union. Systems programming and other minicomputer software were provided by C. Cantor of Emmanuel College. Regular network operations are performed by F. Pavlica of AFGL. The authors are very grateful for the contributions of these and many other people who have been involved in this program.